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HEAT TREATING GUN STEEL

LEVEL II

F. Heiser

March 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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A study was conducted to evaluate the effect of tempering time on the mechanical properties of gun steel, a medium C, Ni-Cr-Mo steel used in cannon tube forgings. The results on small specimen tests show that in tempering at temperatures up to 1100°F, time is not important beyond 60 minutes. Above 1100°F, time becomes a more important factor. For the yield strength range of many tubes, 160-180 ksi, tempering at 1000-1100°F is required. Thus, for

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these tubes, the tempering cycle can be drastically shortened.

Data were also developed for two austenitizing temperatures, 1550°F (which is usually used) and 1750°F (which is used in some furnaces which utilize a high thermal head and allow a short austenitizing cycle). It is demonstrated that the latter would not allow the tube forging requirements to be satisfied, and dictate that austenitizing temperatures must be maintained at lower temperature.

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INTRODUCTION

The tempering of steel can be considered from a variety of viewpoints, from the physical metallurgical to the phenomenological. The user is interested in the latter. It is generally accepted that the optimum combination of properties is achieved by tempering a fully hardened (i.e. martensitic) structure, because while strength decreases, both toughness and ductility increase with increased tempering.

Since tempering involves the precipitation and growth of carbides from the martensitic microstructure, the degree of tempering is influenced both by temperature and time at temperature. The relative importance of each parameter on strength, as measured by hardness, was shown by Hollomon and Jaffe.[1] They showed empirically that hardness and, therefore, strength, after tempering depended on a tempering parameter which was related to $T \log \frac{t}{t_o}$ where "T" is the absolute temperature, "t" is the tempering time and "t_o" is a constant. Thus, the tempering temperature is much more influential than is the tempering time. However, the results also indicate that a variety of T-t combinations can be used to develop the same property.

A similar generalization has not been made for the influences of T and t on ductility and toughness. Studies have been run which show that toughness and ductility increase as tempering temperature increases, but data on the effect of time are sparse, and can be gleaned only from interpretation of various tables and figures showing mechanical properties for specific materials.

1. J.H. Hollomon and L.D. Jaffe. "Ferrous Metallurgical Design" John Wiley & Sons Inc. N.Y. , 1947

Cannon tubes are manufactured from an electric furnace vacuum degassed medium carbon, low alloy Ni-Cr-Mo steel, commonly called gun steel. It is not a standard alloy. As a result, published data on the effect of tempering parameters are non-existent. However, examination of reports from contractors producing cannon tube forgings shows that tempering temperature is a variable in the 1000°F-1100°F range, dependent primarily on yield strength desired, and that tempering times in the 8-10 hour range are commonly used. Since the times appear inconsistent with the empirical relation developed by Hollomon and Jaffe,[1] and because data on the effect of short time tempering on mechanical properties of gun steel did not exist, a study was run to determine the influence of tempering temperature and times on strength, ductility and toughness. Its ultimate aim was to determine if the heat treat cycle for cannon tubes produced by the rotary forging process could be reduced from that used in current practice by the several contractors who produce cannon tube forgings.

MATERIALS AND PROCEDURE

The starting material was a rotary forged cylinder, 18" OD x 8" ID, with the following typical gun steel chemistry:

C	Mn	Si	Ni	Cr	Mo	V	P	S
.33	.62	.15	2.69	1.08	.53	.10	.009	.007

The original material had been press forged as a solid and machined into a preform, 21" OD x 9" ID (The initial ingot size and forging reduction are

1. J.H. Hollomon and L.D. Jaffe. "Ferrous Metallurgical Design" John Wiley & Sons Inc. N.Y. , 1947

unknown). Discs were taken from the cylinder and tensile and Charpy V-notch test bar blanks were machined in the transverse orientation, i.e., the axis of the blank was normal to the radial direction of the disc, and the notch on the Charpy bar was along the axial direction of the cylinder, so that the fracture ran in the radial direction.

The blanks were austenitized for one hour at 1550°F or 1750°F and water quenched. The specimens were then tempered at 900°F-1200°F for times, at temperature, ranging from 15 minutes to 240 minutes. Because tube forgings are usually austenitized around 1550°F, more extensive testing, in terms of varying tempering temperatures, was performed with that austenitization practice than with the 1770°F austenitization temperature. The latter data were generated to determine if the austenitization temperature were critical. It has been considered that the higher temperature might be beneficial, considering that the austenitization time was so short.

After heat treating, tensile tests were conducted at room temperature, Charpy V-notch tests were conducted at -40°F (per the tube forging specification) and hardness measurements were made. The data of interest were the Yield Strength (0.1% offset), Reduction in Area, Charpy Impact Energy and Hardness (R_c).

RESULTS AND DISCUSSION

Effect of Time

The results for the 1550°F and 1750°F austenitizing temperatures are shown in Tables I and II, respectively. In attempting to analyze the data, a computer program was devised by P. Dembowski[2] to plot the data in three dimensions, whereby a specific property was plotted against both tempering temperature and tempering time. From these graphs, it was then possible to plot iso-property lines, which indicate tempering parameters which resulted in the same property, e.g., the temperature and time to yield 160,000 psi yield strength or 15% RA or 25 ft-lbs, etc. Using these contour plots, it would be possible to determine the tempering parameters to develop an optimum combination of properties. This technique is being reported separately.

A more conventional approach is shown in Figures 1-8 which show the effect of tempering time on properties, for constant austenitizing conditions and tempering temperatures. An observation which is common to all the material except that tempered at 1200°F is that the yield strength is affected very little by times after approximately 60 minutes. From 60 minutes to 240 minutes, the yield strength is only slightly affected. However, the strength of the material tempered at 1200°F continually decreases with time, e.g., the decrease from 15 minutes to 240 minutes is in the order of 45,000 psi. This is perhaps a manifestation of the observation that there is a limiting tempering temperature for steel

2. P. Dembowski, "Computerizing the Effect of Tempering on the Mechanical Properties of a Ni - Cr - Mo Steel," Watervliet Arsenal Technical Report No. ARLCB-TR-77030 Watervliet, N.Y., June 1977

above which the decrease in strength is precipitous. These data indicate that the cut-off tempering temperature for the gun steel tested is between 1100°F and 1200°F.

Examination of the data also shows the difficulty which might be expected in trying to heat treat to a yield strength lower than 160,000 psi. It would be necessary to temper above 1100°F, where the influence of temperature and time are starting to be more significant. Extra care and closer control of conditions would have to be exercised.

The ductility (RA) and toughness (Cv) show a similar effect of time. Below 1100°F, the major effect takes place in the first 90 minutes. At 1100°F and higher, the ductility and toughness continue to rise with increasing time. As has been reported many times, the scatter in the data, particularly the RA, is more noticeable than that for the yield strength.

Effect of Austenitizing Temperature

There is a significant effect of austenitizing temperature. Figures 9-11 compare the results from the two austenitizing temperatures. The results from the 1750°F austenitizing appear to be independent of the tempering temperature for all three properties. However, the results from the 1550°F austenitizing show the usual result, viz., strength decreases, and ductility and toughness increases as tempering temperature increases. The ductility and toughness for the 1750°F austenitized

material are consistently lower than for the 1550°F material, with the difference increasing with tempering temperature. The strength passes through a transition, with the yield strength of the material austenitized at 1550°F, being higher when tempered at 900°F, but being lower when tempered at 1100°F.

The effect of austenitizing temperature on RA and Cv has been reported previously. It has been associated with a grain growth effect at the higher temperature. The apparent effect on strength is peculiar. It suggests that the larger grained material (1750°F austenitization) is not influenced by changing tempering temperatures.

Relation to Requirements

When a part is heat treated, there is a requirement which must be met. The heat treater usually uses hardness as a guide which he can measure non-destructively. Since the major impetus for this work was to develop parameters for heat treating tube forgings, tempering treatments to meet their requirements were examined. The data have prime applicability to the 160-180 ksi yield strength range. To meet the requirements in that strength range, the tempering cycles shown below would be appropriate:

YS	Required RA	Cv	Tempering Temperature	Time
160-170 ksi	25%	15 ft-lbs	1050°F	2-4 Hrs.
170-180 ksi	25%	15 ft-lbs	1000°F	2-4 Hrs.

In both cases, austenitizing at around 1550°F would be required. None of the material austenitized at 1750°F would meet the requirements.

CONCLUSIONS

These data demonstrate a variety of phenomena. They show that it is possible to develop desired properties with very short exposure to tempering temperature. Prolonged times are unnecessary and costly when tempering at 1100°F or less. This conclusion is important to the heat treat system used with the rotary forge machine. There, the continuous horizontal barrel furnace being used relies on tempering times in the range of 2-4 hours at temperature to meet mechanical property requirements and production rates.

The data also indicate the sensitivity of mechanical properties to exposure time above a certain temperature. This temperature was not specifically determined, but certainly above 1100°F, time can be an important factor. Since this is the tempering range to achieve less than 160 ksi YS, any requirements below that strength level will require more precise monitoring.

In the original concept of the horizontal continuous barrel heat treat system, consideration was given to utilizing a thermal head to heat the tube quickly. Temperatures in excess of 1600-1700°F would have been reached. Preliminary data developed on tubes and on small specimens showed that this was undesirable. The furnace was therefore designed to limit the austenitizing temperature to 1600°F.

The data shown here again verify and support the previous decision. Hardening from 1750°F would not permit the tube forging requirements to be met. The insensitivity of the material austenitized at 1750°F to changes in tempering temperature was unexpected. No satisfactory rationale can be provided for this behavior.

When using these data, it must be remembered that they were developed by heat treating small specimens. Thus, transformation to martensite during hardening is virtually assured. When a thick wall tube is hardened, this transformation is not guaranteed. Thus the results shown may not be used, per se. However, they can be used as guidelines. The conclusion that tempering times can be shortened is not influenced by section size, if one can measure when a component reaches temperature. If this is not possible, empirical adjustments must be made.

TABLE I
MECHANICAL PROPERTIES
(AUSTENITIZE - 1550°F - 1 Hr.)

Tempering Temperature	Tempering Time	Yield Strength	%RA	C_V(-40°F)	R_c
900°F	15 Min.	186 ksi	43%	14 ft-lbs	45
	30	180	47	12	44
	45	178	44	13	43
	60	178	42	16	43
	90	176	47	14	44
	120	176	42	13	43
	150	175	43	15	43
	180	176	44	13	44
	210	176	43	15	42
	240	175	42	13	43
1000°F	15	178	41	15	44
	30	172	45	17	43
	45	173	43	17	43
	60	172	43	18	41
	90	172	47	15	43
	120	172	48	17	43
	150	171	46	19	43
	180	171	45	20	43
	210	171	49	20	42
	240	171	44	20	42
1050°F	15	173	48	20	43
	30	170	47	20	43
	45	170	50	19	43
	60	168	50	22	43
	90	168	47	24	43
	120	168	51	25	43
	150	165	49	22	42
	180	171	48	23	43
	210	165	47	25	42
	240	165	50	26	42
1100°F	15	171	45	18	42
	30	168	48	25	43
	45	170	47	23	42
	60	168	48	26	42
	90	164	48	29	41
	120	165	48	24	42
	150	160	50	30	41
	180	163	52	32	41
	210	160	52	30	41
	240	163	50	36	40

TABLE I (Continued)

Tempering Temperature	Tempering Time	Yield Strength	%RA	C_V(-40°F)	R_C
1200°F	15 Min.	171 ksi	46%	21 ft-lbs	42
	30	162	52	36	39
	45	155	54	44	38
	60	150	53	49	37
	90	141	55	51	35
	120	138	55	55	33
	150	133	60	55	33
	180	133	57	56	32
	210	129	58	57	31
	240	126	58	57	31

TABLE II
MECHANICAL PROPERTIES
(AUSTENITIZE - 1750°F - 1 HR.)

Tempering Temperature	Tempering Time	Yield Strength	%RA	C_V	R_C
900°F	15 Min.	176 ksi	43%	11 ft-lbs.	43
	30	171	42	11	41
	45	170	44	12	40
	60	170	41	11	40
	90	170	47	11	40
	120	167	45	11	40
	150	169	42	11	40
	180	169	43	12	39
	210	169	40	11	41
	240	169	45	12	40
1000°F	15	177	42	11	43
	30	172	43	11	41
	45	171	47	10	40
	60	170	40	11	40
	90	170	44	12	40
	120	170	41	11	40
	150	170	41	11	40
	180	169	43	11	40
	210	171	44	14	39
	240	169	44	11	39
1100°F	15	176	44	11	43
	30	171	44	10	38
	45	169	45	12	38
	60	171	44	11	40
	90	168	42	11	39
	120	169	43	13	38
	150	168	43	12	40
	180	170	43	13	39
	210	171	41	10	40
	240	169	44	12	39

KEYS FOR FIGURES

Figures 1 - 8	Rc - 0	
	YS - ●	
	RA - X	
	Cv - ⓧ	
Figures 9 - 11 -	YS - 0 (1550°F) and ● (1750°F)	
	RA - ⓧ (1550°F) and X (1750°F)	
	Cv - ⊕ (1550°F) and + (1750°F)	

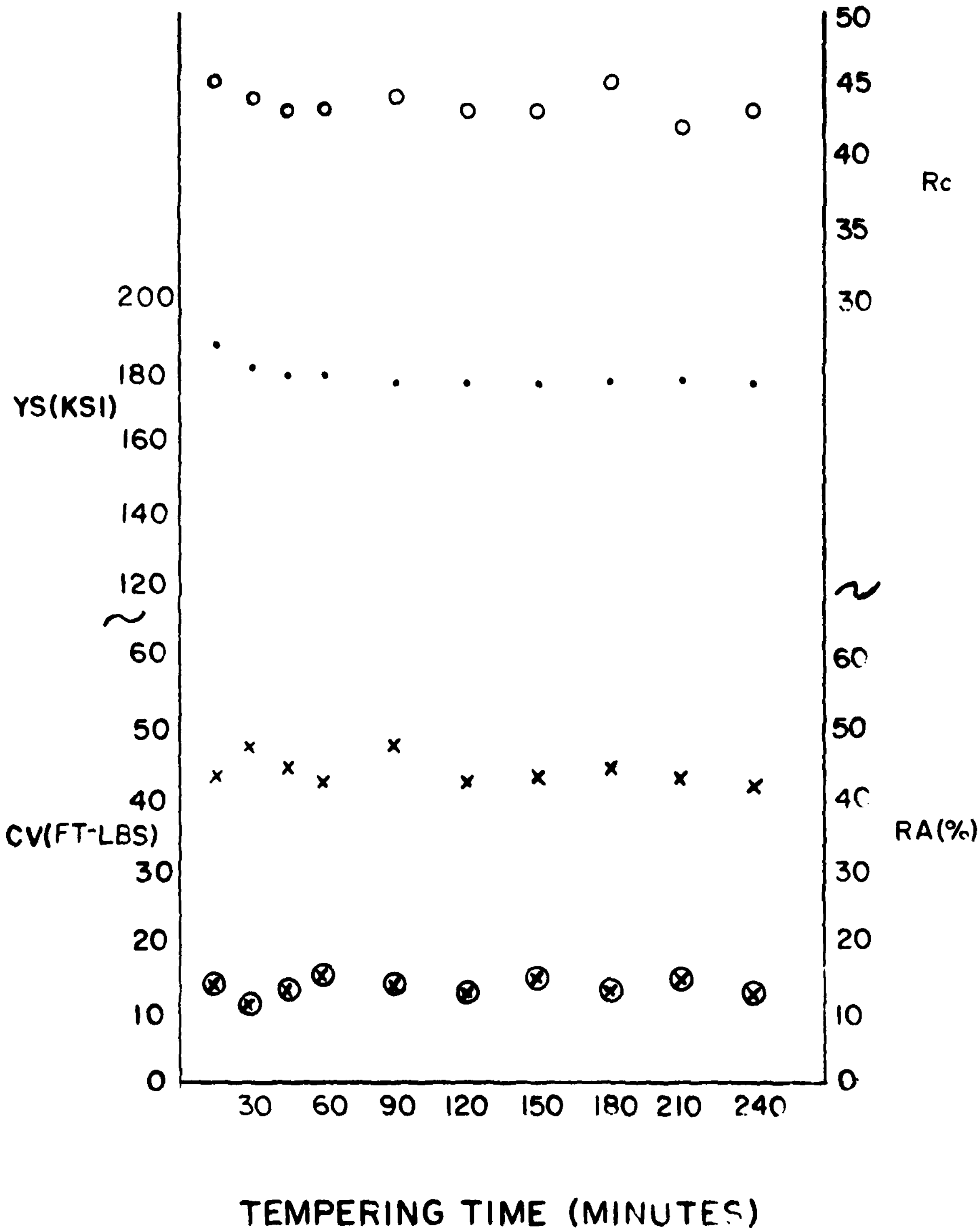

Fig. 1 - Effect of Tempering Time at 900°F - Austenitized at 1550°F.

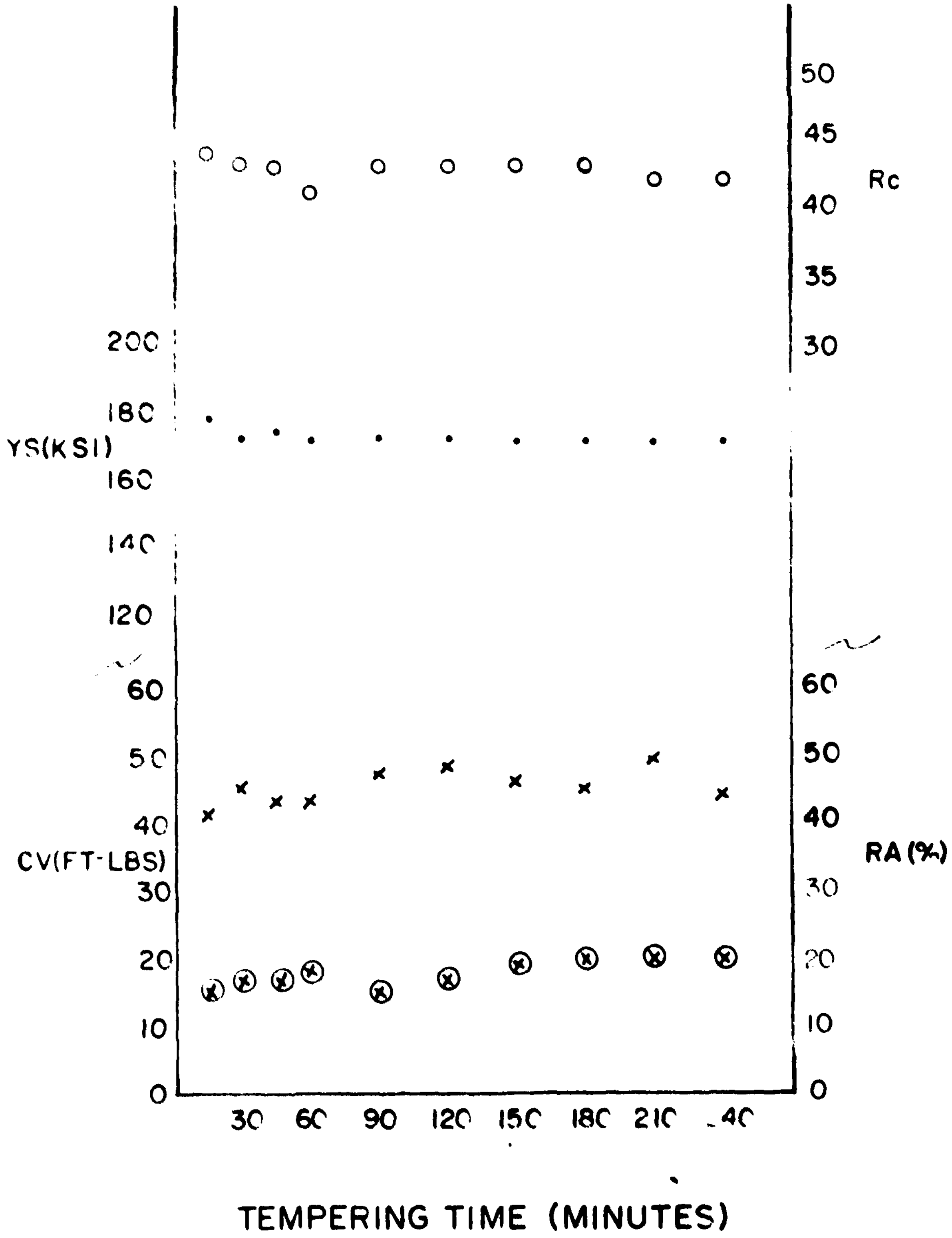

Fig. 2 - Effect of Tempering Time at 1000°F - Austenitized at 1550°F.

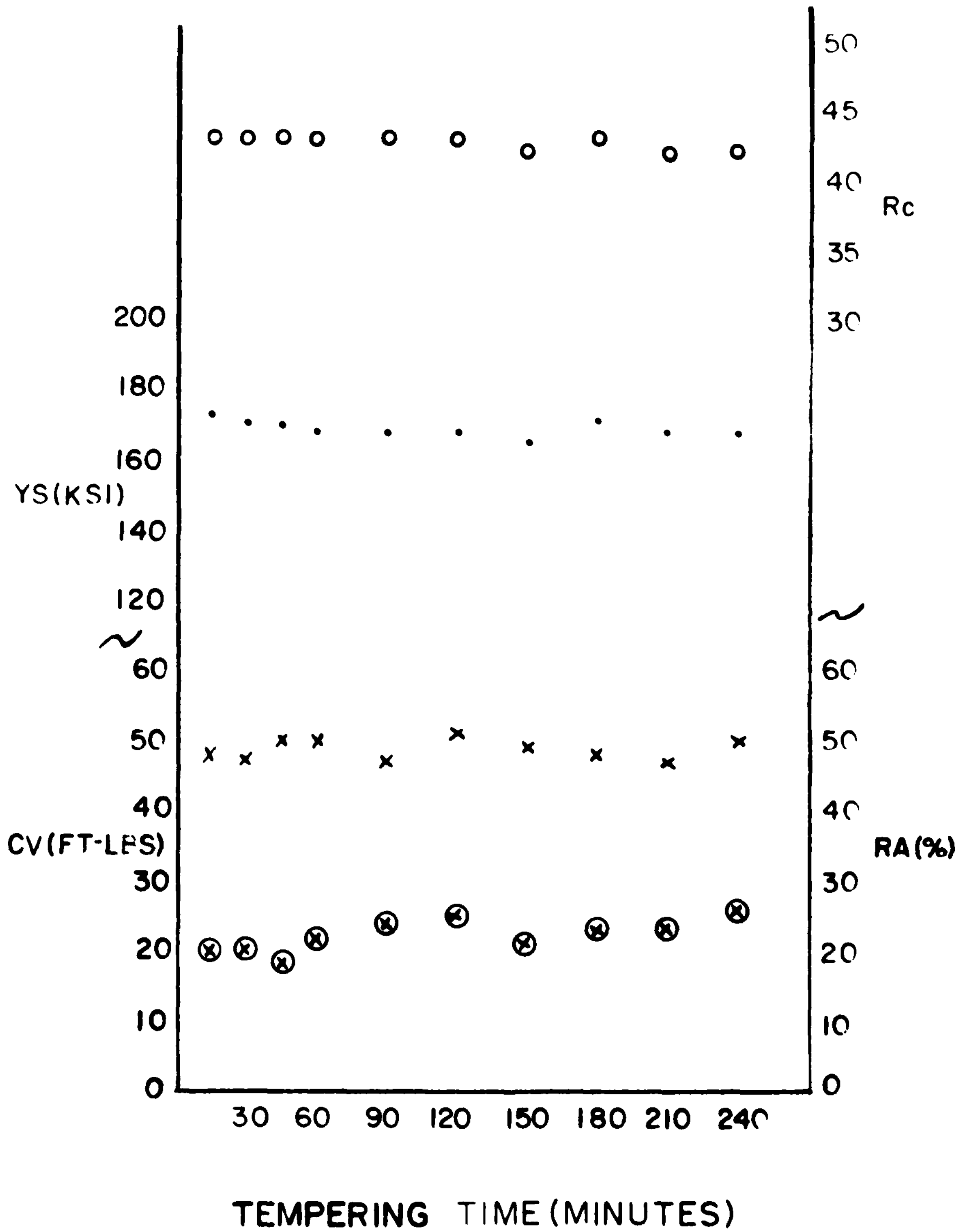

Fig. 3 - Effect of Tempering Time at 1050°F - Austenitized at 1550°F

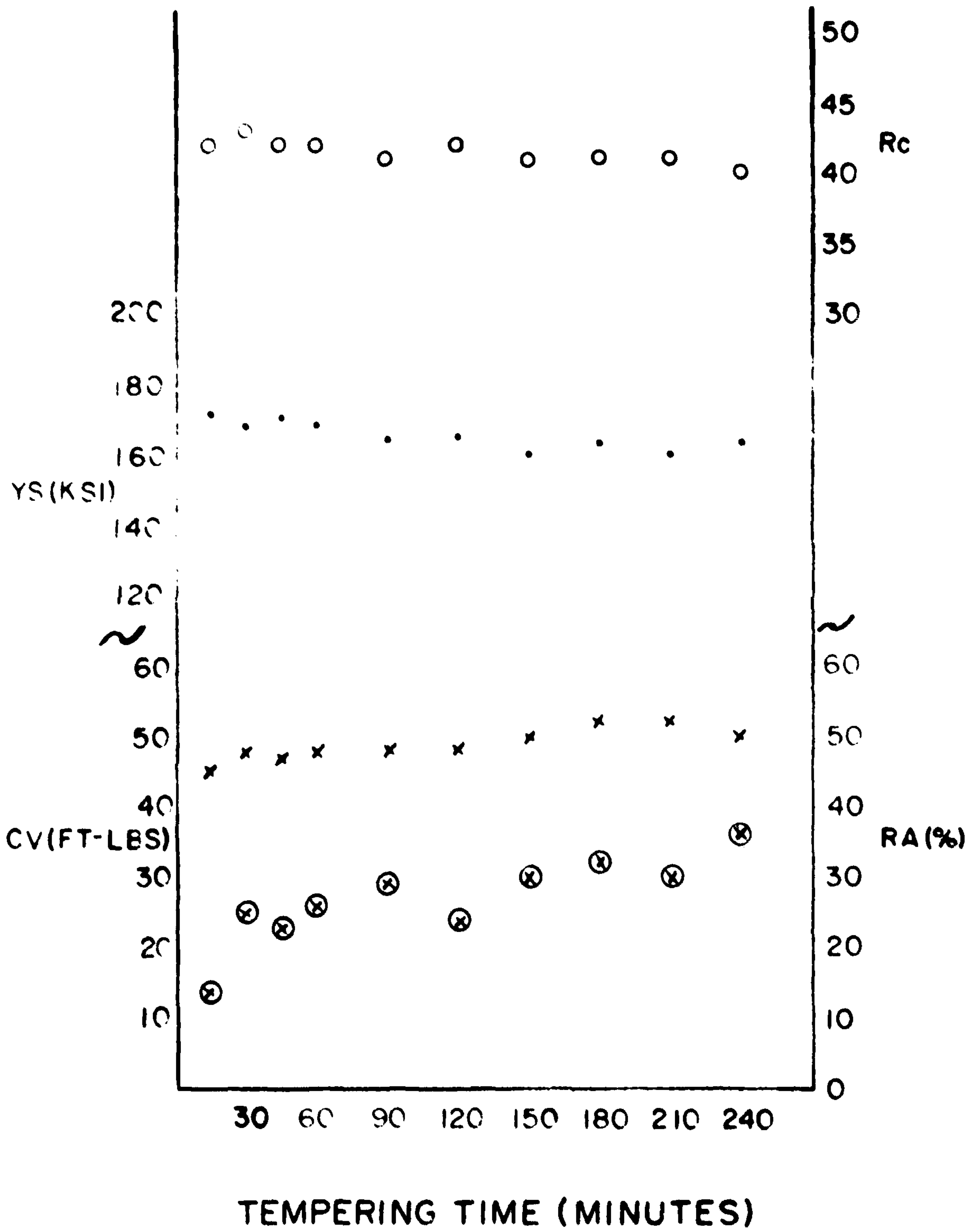

Fig. 4 - Effect of Tempering Time at 1100°F - Austenitized at 1550°F.

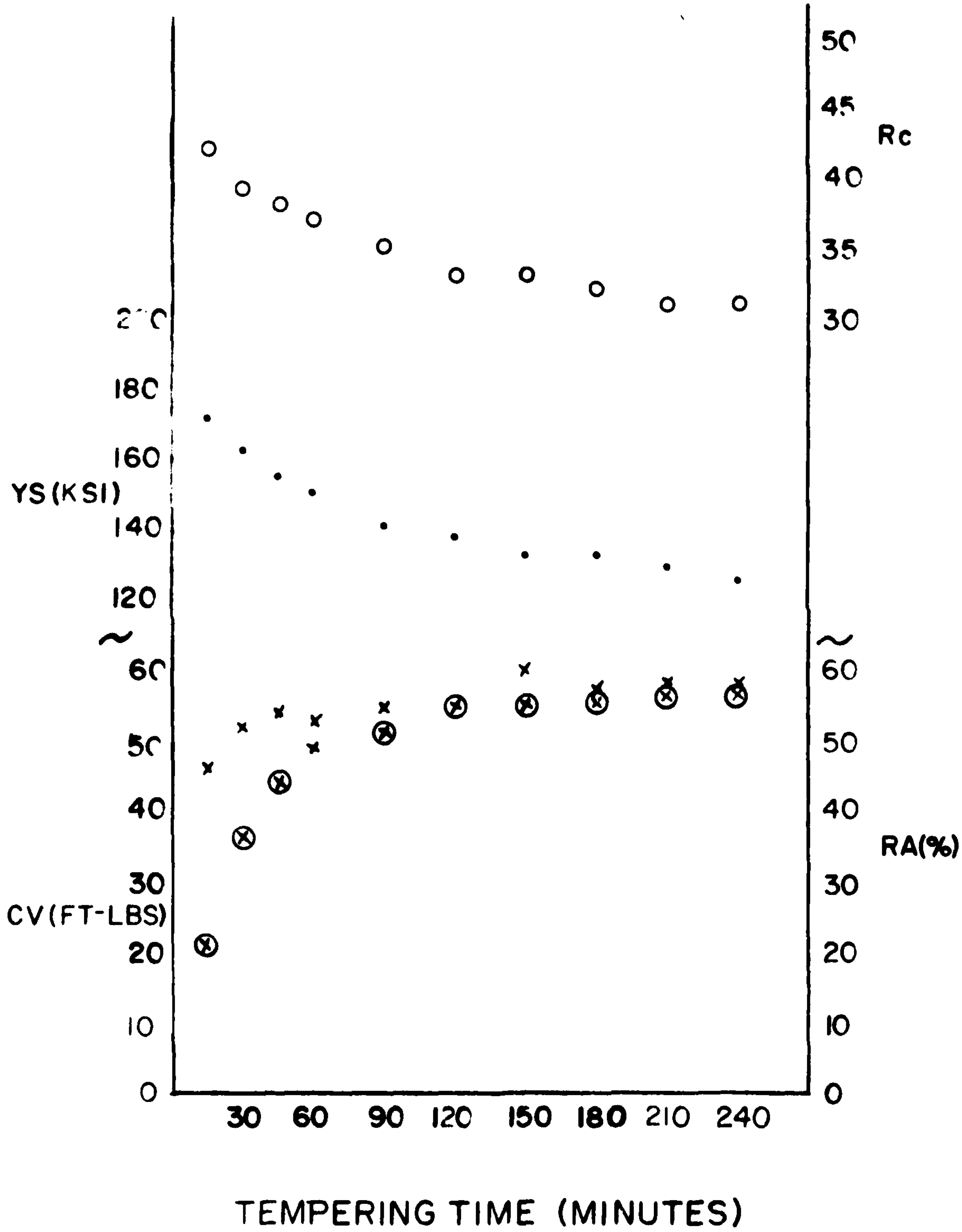

Fig. 5 - Effect of Tempering Time at 1200°F - Austenitized at 1550°F.

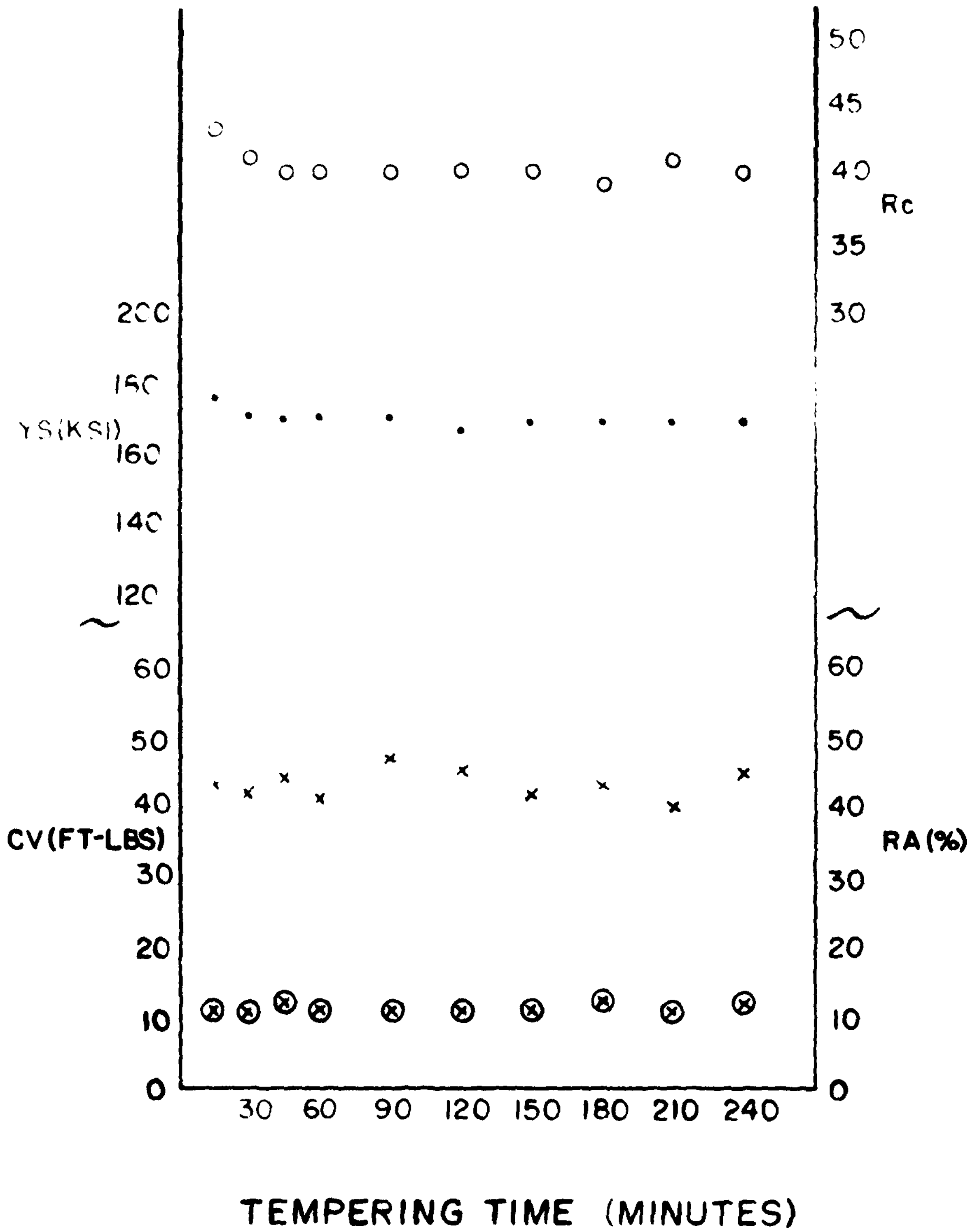

Fig. 6 - Effect of Tempering Time
at 900°F - Austenitized
at 1750°F.

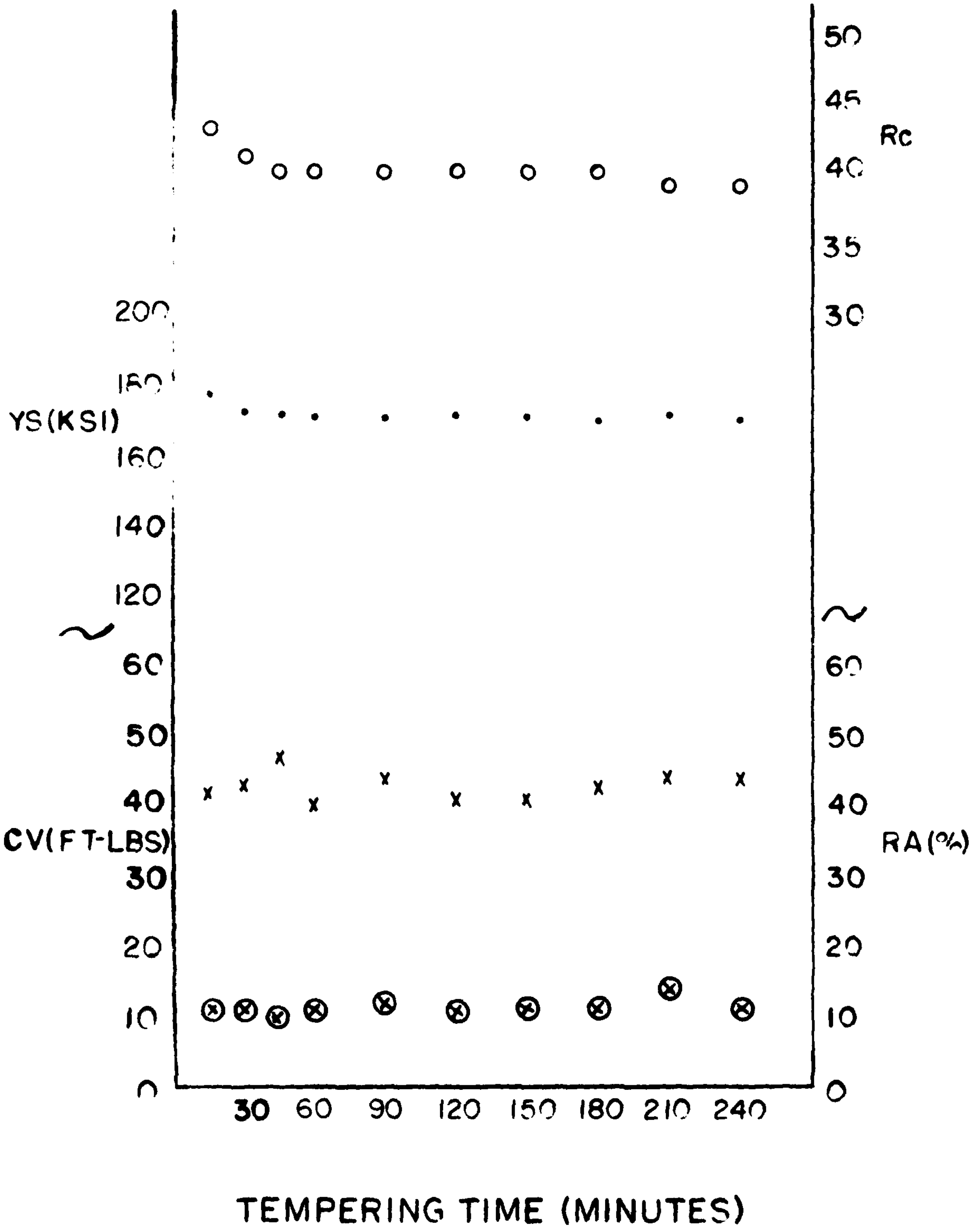

Fig. 7 - Effect of Tempering Time at 1000°F - Austenitized at 1750°F.

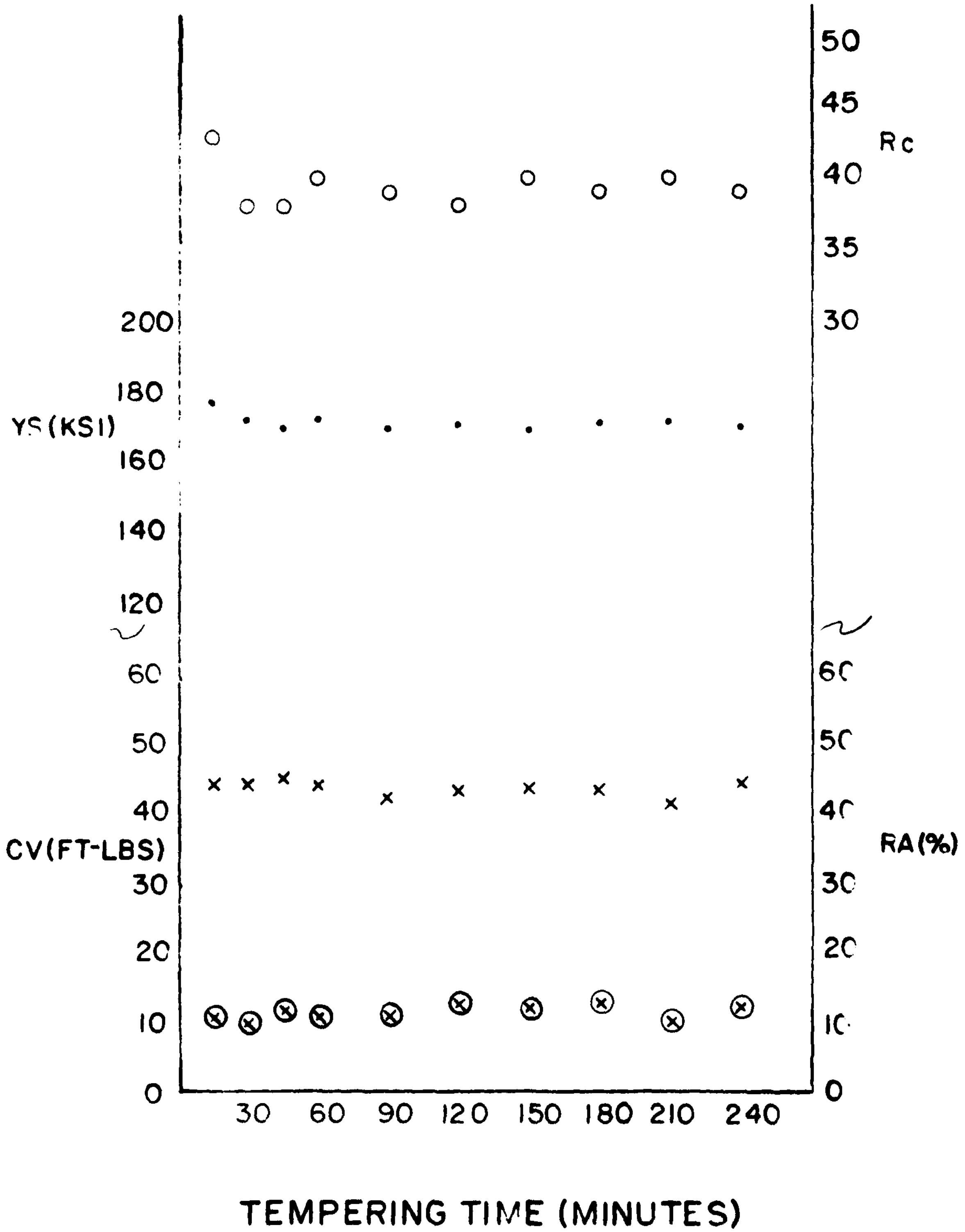

Fig. 8 - Effect of Tempering Time at 1100°F - Austenitized at 1750°F.

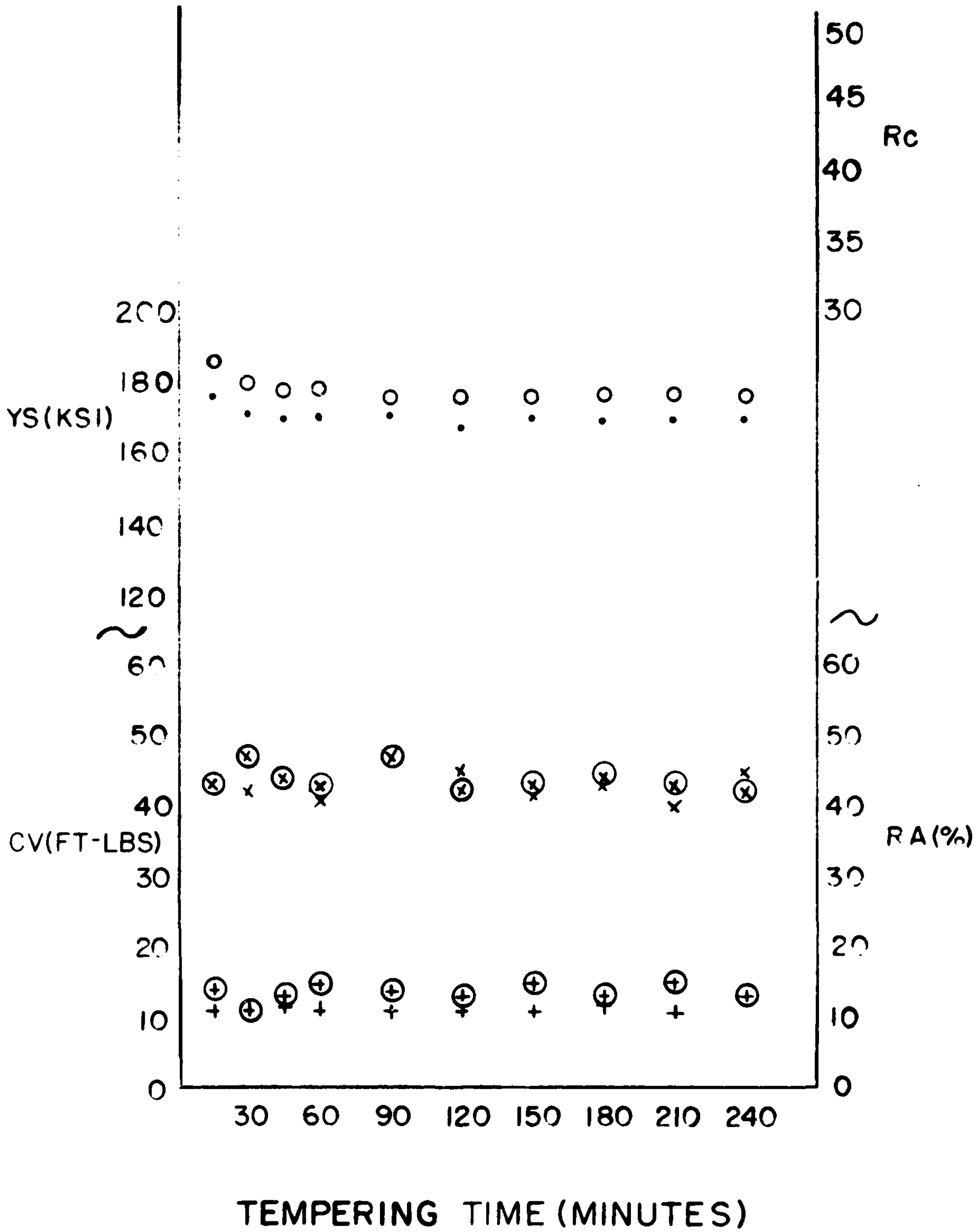

Fig. 9 - Effect of Tempering Time at 900°F - 1550°F vs. 1750°F Austenitize.

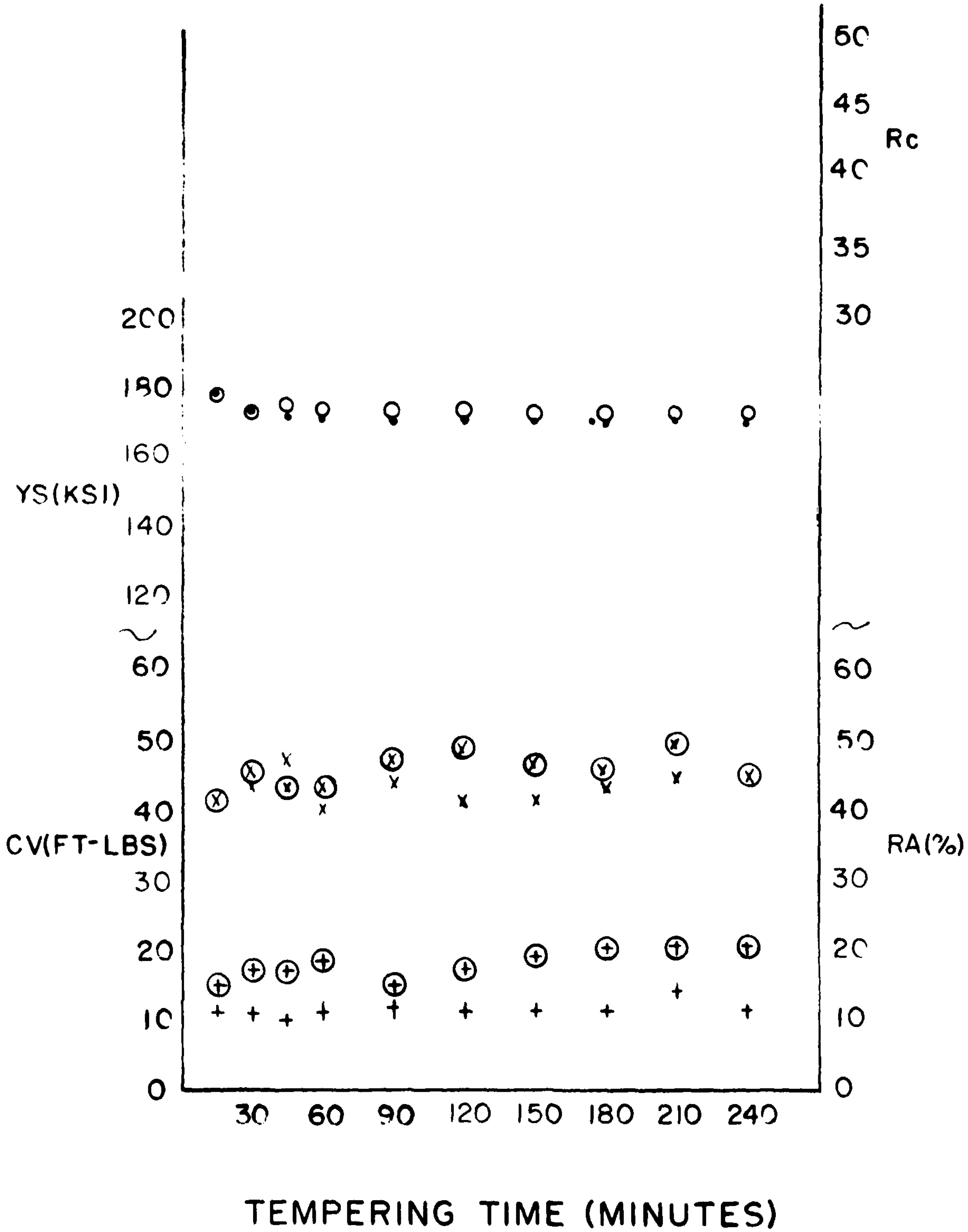

Fig. 10 - Effect of Tempering Time at 1000°F - 1550°F vs. 1750°F Austenitize.

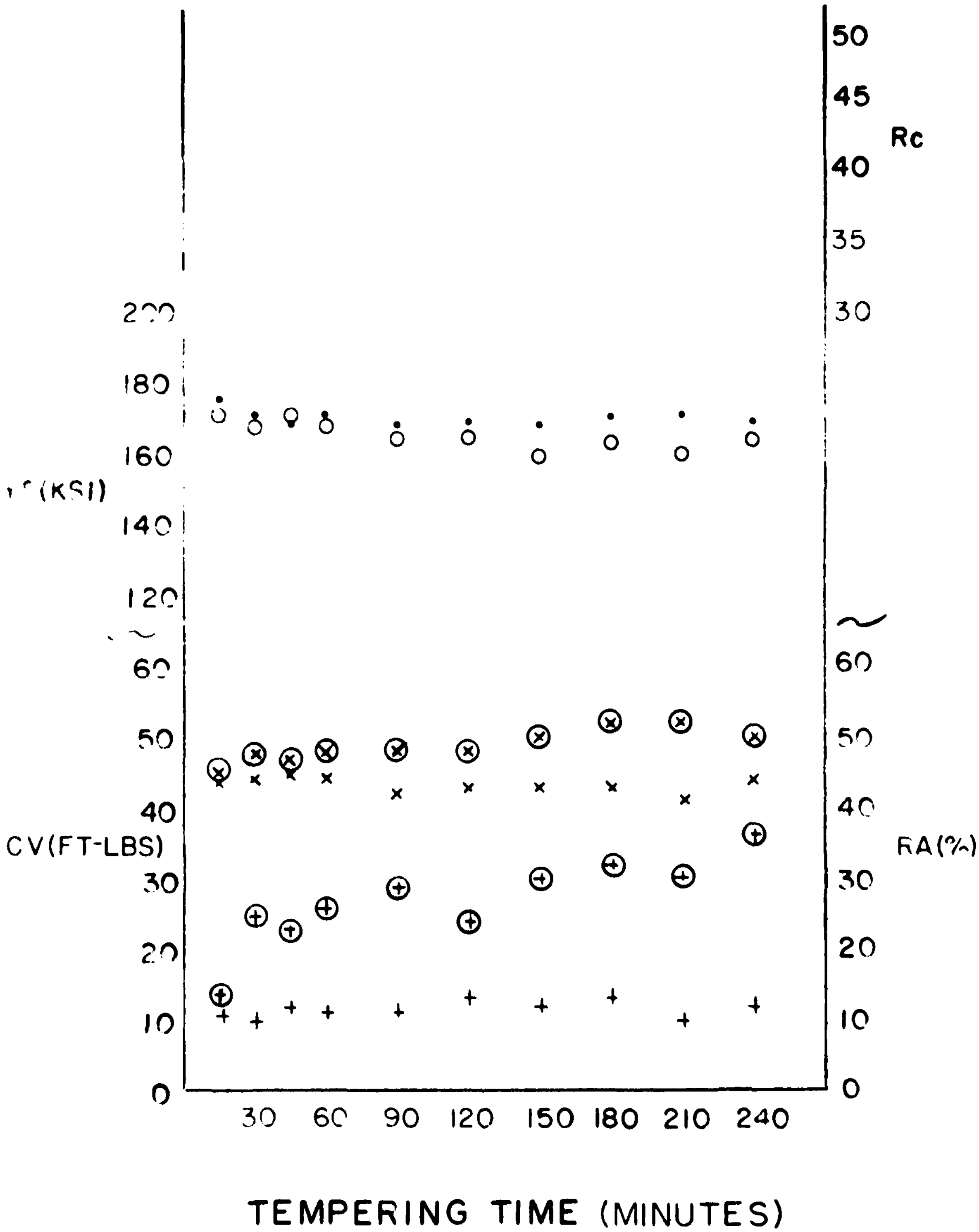

Fig. 11 - Effect of Tempering Time at 1100°F - 1550°F vs. 1750°F Austenitize

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